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An Efficient Diode-pumped Nd:YAG laser with 451 W of CW IR and 182 W of pulsed green output

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Abstract

We have demonstrated a compact and efficient diode-pumped Nd:YAG laser with 451 W of IR output. This laser also generated 182 W of pulsed green output using AO Q-switched intracavity doubling with an LBO crystal.

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Summary

The availability of high-power laser diodes with increased lifetime and reduced cost has generated much interest in using them to replace lamps for pumping Nd:YAG.[1,2] We have recently demonstrated 451 W of CW IR and 182 W of Q-switched green output from a diode-pumped Nd:YAG laser. This laser uses a novel side-pumped design developed for efficient coupling of high-power diode radiation into a close-coupled pump chamber enclosing the Nd:YAG laser rod, as illustrated in Fig. 1. The pump chamber with diffuse reflector improves the pump uniformity, which is important for efficient high-power laser operation. The compound parabolic concentrators (CPCs) compress the pump radiation through narrow slits in the walls of pump chamber with a transmission of 90-95%. CPCs are capable of roughly three times the spatial light compression of conventional imaging optics and enable us to use less than 4% of the pump chamber wall area for the slit opening. This design leads to highly efficient recycling of pump light, improved pump homogeneity, and lower sensitivity of the laser output to shifts of the diode wavelength. In addition, the large acceptance angle of the CPCs (~ 7°) allows us to use low cost diode packages with simple micro lenses for the diodes. Figure 2 shows the picture of the compact head design with a head length of 6 inches. Patents on the design are pending.

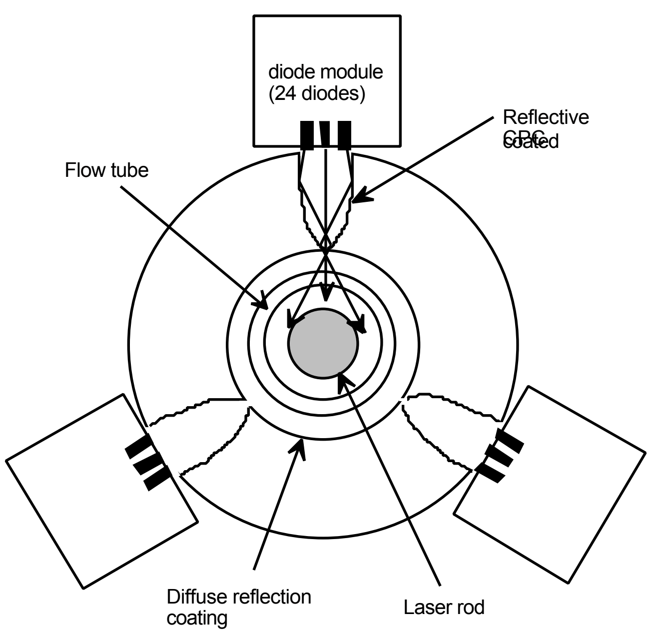

Figure 1. A diode-pumped solid-state laser (DPSSL) design using compound parabolic concentrators (CPCs) and closed coupled pump chamber.

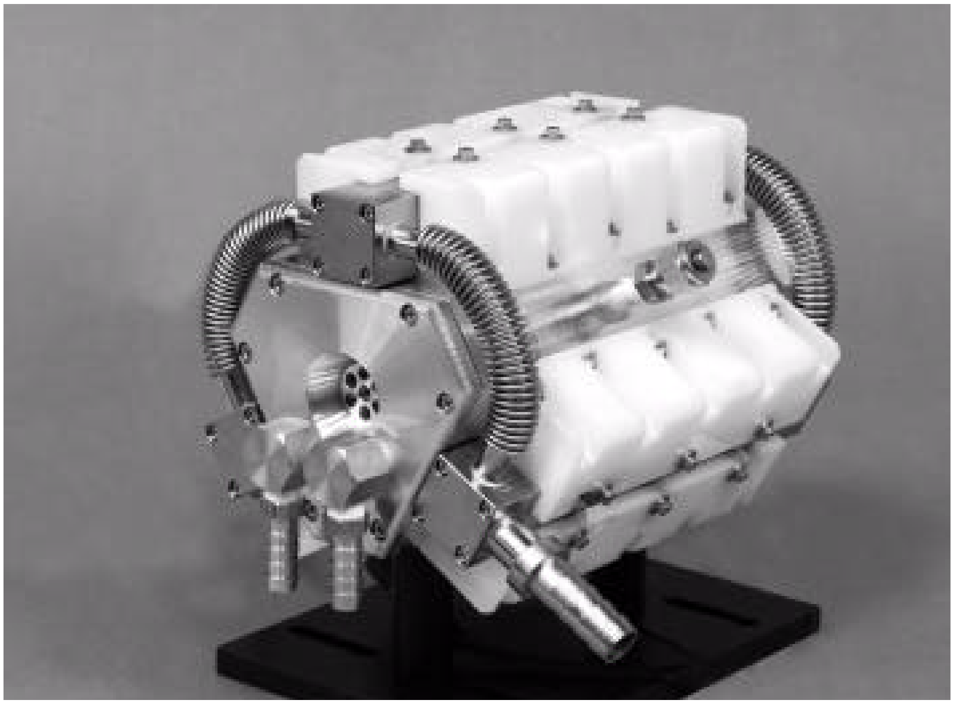

Fig. 2 The DPSSL pump head, its length is about 6 inches.

The 20-W-rated diode bars from Opto-Power were passively cooled and operated CW. With a 5-mm-dia. Nd:YAG rod of 1.0% doping, we have achieved CW IR output of greater than 450 W using a short, flat-flat resonator with a 20% output coupler. The IR output versus diode power is shown in Fig. 3. The output of 451 W was obtained with a diode power of ~1180 W at a diode current of 27.5 A. Greater laser power can be achieved with higher diode current because the diodes are rated at 30 A. An optical-to-optical efficiency of 40% and an electrical-to-optical efficiency of 13% was achieved when the laser output was between 300 to 400 W. The slop efficiency of this CW operation was approximately 50%. For pulsed laser operation, we employed

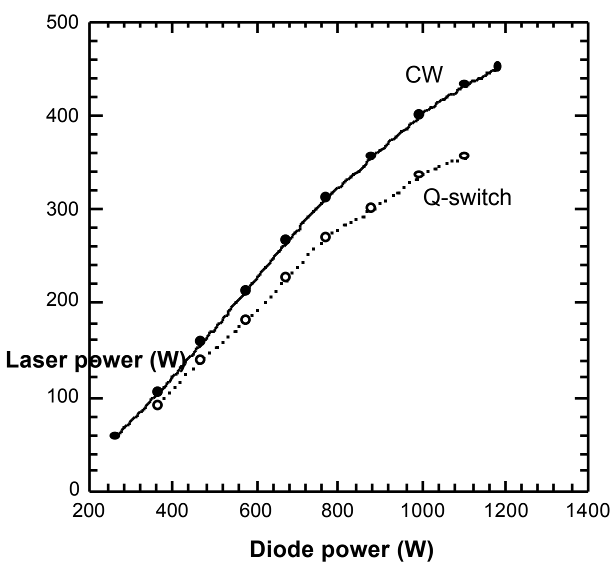

Figure 3. CW and Q-switched output of the DPSSL with a short flat-flat resonator at 13 kHz. Two AO Q-switches were used for pulsed output.

two AO Q-switches (i.e., compression wave) for sufficient cavity hold-off. They were placed orthogonally to each other for the best performance. The Q-switched laser output at 13 kHz using a 30% output coupler is plotted in Fig. 3. An output greater than 350 W with pulse duration of 70-80 ns (FWHM) was achieved with a diode power of ~1100 W. The typical ratio of pulsed to CW output was ~85%.

For many industrial applications such as cutting, drilling, trimming, and marking, medical applications such as laser surgery,[3] and for pumping dye and Ti-sapphire lasers in scientific research systems, high PRF second harmonic (green) output is needed. To achieve this, we employed intracavity frequency doubling using an L-resonator configuration with a green transmitting 45° dichroic. Figure 4 shows Q-switched IR output at 13 kHz when the L-resonator was configured with a 20% output coupler and the doubling crystal was removed. We also found that more effective Q-switch hold off could be achieved with a lower doped Nd:YAG rod because of more uniform pumping. A Nd doping level of 0.7-0.8% was found to have the best performance for pulsed IR and green generation when a 5mm diameter laser rod was used.

We have employed both KTP and LBO nonlinear crystals for intracavity doubling. The gray-tracking problem associated with KTP crystals prevented them from reliable laser operation, especially for a green output above 100 W. As a result, most of our works presented here were done with LBO (5x5x18 mm^3). The doubling crystal was placed between the 45° dichroic and one of the cavity mirrors, which also had a dichroic coating for green transmission. This setup generated two green output beams with lower LBO thermal loading than a single output scheme (i.e, by replacing the end dichroic mirror with a HR). At 13 kHz, a combined green outputs greater than 182 W was achieved at a diode power of ~1 kW, as illustrated in Fig. 4. This result represents an electrical-to-green efficiency of 5.9%. The ratio of green output to Q-switched IR output for the laser was typically about 70%. The green pulse duration at 182 W was about 60 ns FWHM, which was about half of the pulse duration of the intracavity IR. It is worth noting that the power rollover of the green output did not occur in the IR. We found this was partly a result

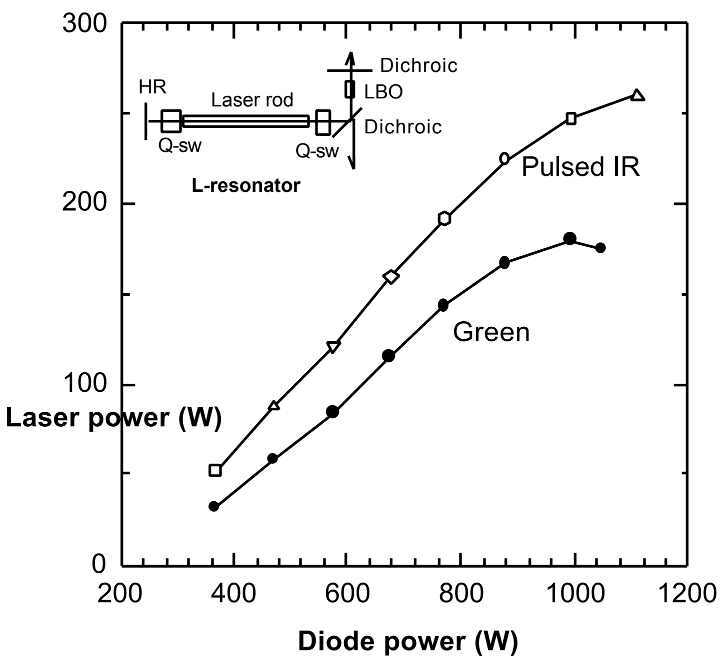

Figure 4. Pulsed IR and green outputs of the DPSSL with an L resonator at 13 kHz using an intracavity LBO crystal.

of ineffective Q-switch hold-off at higher power when the cavity output coupling was low with a doubling crystal. Note that the equivalent output coupling with a doubling crystal was about 5-10% in this case. Thermal and nonlinear effects in the doubling crystal may also have caused the power rollover. The pulse-to-pulse energy fluctuation was measured to be less than 1.5%. The laser PRF can be lowered to 7 kHz without cavity hold-off problem, but the laser power decreases significantly (~30%) at this PRF. The near and far field of the green output was typically a Gaussian-like profile with a beam divergence ~20 times that of a diffraction limited beam.

To demonstrate the reliability of this laser for industrial-type applications, we have operated it in a continuous, hands-off mode for greater than 1000 hours using an LBO crystal. The average output during this test was 177 W with a constant diode current of 24 A. Degradation of the output due to the laser diodes and the LBO crystal was negligible. Minor coating degradation of cavity optics and contamination of flow tube were discovered and fixed. A laser power degradation rate as low as 0.001%-0.003% per hour has been demonstrated with thousands of hours of operation accumulated. To our knowledge, this laser demonstrated highly reliable operation of a DPSSL with a world record green output using intracavity frequency doubling. This work was performed under the auspices of U.S. Department of Energy at the Lawrence Livermore National Laboratory, under Contract W-7405-Eng-48.

Reference

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